International Journal of Advances in Applied Sciences (IJAAS)
Vol. 11, No. 3, September 2022, pp. 263~276
ISSN: 2252-8814, DOI: 10.11591/ijaas.v11.i3.pp263-276

Advanced optimal GWO-PID controller for DC motor

Ghada Adel Aziz[1], Salam Waley Shneen[2], Fatin Nabeel Abdullah[1], Dina Harith Shaker[1]
[1]Department of Electromechanical Engineering, University of Technology, Baghdad, Iraq
[2]Nanotechnology and Advanced Material Research Center, University of Technology, Baghdad, Iraq

Article Info

Article history:

Received May 6, 2022
Revised Jul 31, 2022
Accepted Aug 28, 2022

Keywords:

Direct current motor
Grey wolf optimization
PID controller

ABSTRACT

The current work aims to use traditional control algorithms and advanced optimization algorithms that was chosen for its ease of control and the possibility of using it in many industrial applications. By setting the appropriate specifications for the simulation model and after conducting the planned tests that simulate different applications of the motor's work within electrical systems, the results proved to obtain good performance of the motor's work, better response, high accuracy, in addition to the speed. The goal is to design and tune a proportional–integral–derivative (PID) controller by grey wolf optimization (GWO) using transfer function (T.F) for a direct current (DC) motor. To adjust the parameters of the traditional controllers using the optimum advanced, an appropriate mechanism and technology from the advanced optimization techniques were chosen, as the gray wolf technology algorithm was chosen as an optimization technique and integral time absolute error (ITAE) to adjust the parameters of the traditional PID controller.

Corresponding Author:

Salam Waley Shneen
Nanotechnology and Advanced Material Research Center, University of Technology
Al-Sinaa' Street, 10066, Baghdad, Baghdad, Iraq
Email: salam.w.shneen@uotechnology.edu.iq

1. INTRODUCTION

Electric motors are generally used in many systems, including household, military, medical and industrial [1], [2]. Direct current (DC) motors are considered one of the most important electric motors [3]–[5]. They have specifications that make their choice to move many machines within different applications [6]–[8]. It is the most appropriate technically with high performance and spatiality, occupying less place due to its small size [9]–[11]. DC motors have occupied a wide range of application fields due to their high performance. DC motors include conventional DC and brushless DC electric motor (BLDC) [12]–[14].

Conventional control systems handle errors resulting from the work of linear systems, any adjustment process for their parameters according to the linear system is designed [15]–[17]. An algorithm is developed to suit the system that needs a control unit to improve its performance [18]–[20]. In order to improve the performance of the work of linear systems and the shortcomings of traditional performance [21]–[23]. Many solutions were found, including the advanced optimization [24]–[26]. They simulate the hunter and prey and the iteration process as a result of similar cases and experience, including the genetic algorithm (GA) and Particle swarm optimization (PSO) as well as the wolves grey wolf optimization (GWO) and there are other ways [27]–[29].

In the current work, the GWO algorithm was chosen to adjust parameters the traditional proportional–integral–derivative (PID) controller to improve the working performance of the DC motor. To control the motor speed no it is necessary to specify a target function such as integral time absolute error (ITAE). The work of this type of techniques depends on the creation of a random number of the hunting group and the target function determines the hunting behavior and works to estimate the location of the prey through iterative processes to obtain the optimal location of the prey.

2. DC MOTOR AND SIMULATION MODEL

The electric motor works to produce mechanical energy through the torque arising from the passage of an electric current in the coils of the motor [30]–[32]. First, which in turn acts as an influence in the magnetic circuit in the motor and thus produces a magnetic driving force. Second, which in turn generates a torque to rotate the moving part [33]–[35] which is the rotating part of the electric motor, which produces kinetic energy or mechanical [36]–[38]. The electric motor has special specifications that make the selection process for any application easy [39]–[41]. Such as rotational speed, number of poles, capacity, current, and voltage. according to the manufacturer, and each quantity has a symbol and amount. Table 1 represents the specifications of a DC motor that is intended to perform a computer simulation. To represent it mathematically first and to find the transformation function which is used in building the simulation model. A working algorithm is developed to simulate the operation of the engine first without quantum units. Secondly, the engine is run with the traditional control unit and compared with the previous case. Third, the simulations are carried out with the optimized advanced technique and the comparison with the previous cases. After the simulation, it is possible to work on the appropriate design to control the work of the electric motor by setting an algorithm for better performance, higher speed and accuracy in quality to reach a state close to ideal in performance. In Figure 1 show the simple model for DC motor. In Figure 2 show the block diagram for DC motor at Tf = 0 (no load). In Figure 3 show the block diagram for DC motor with Tf (load).

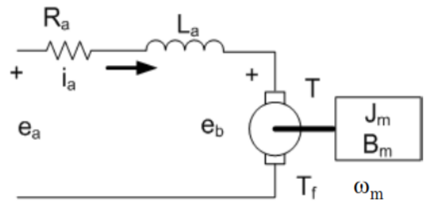


Figure 1. Simple model for DC motor

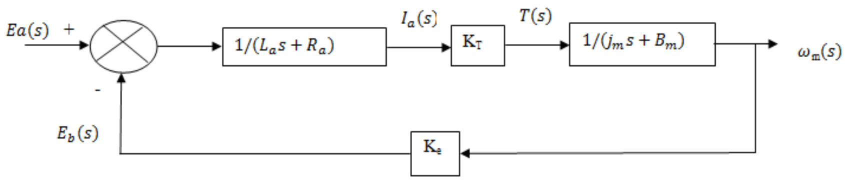


Figure 2. Block diagram for DC motor at Tf = 0 (no load)

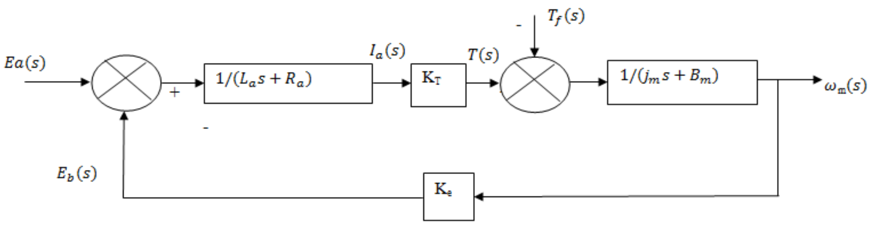


Figure3. Block diagram for DC Motor with Tf(load)

The electric motor has an electric part and it can be put into a mathematical model with equations through which the theoretical specifications can be obtained and the ideal calculations are calculated through it. Equations (1) and (2) include both voltage and power, respectively. The electric motor has a mechanical second part that can be represented in equations (3) and (4) for speed and torque straight [42]–[44].

$$e_a = i_a . R_a - e_b V$$
$$e_b = K_e . \omega_m V \quad (1)$$

Where, K_e = back emf constant, ω_m = motor speed (rad/sec)

$$e_a = (1.2 * 2) + (0.06 * 500) = 32.4\ Volt$$
$$P = \omega_m . TV \quad (2)$$

Where, P = shaft power, T = motor torque

$$P = 500 * 0.108 = 54\ watt$$

Where, $e_a(t)$ = armature terminal voltage, $i_a(t)$ = armature current, R_a = armature resistance, L_a = armature inductance, $e_b(t)$ = back emf.

$$\omega_m = \frac{K_T . e_a - (T - T_f) . R_a}{K_T . K_e}$$
$$\omega_m = \frac{e_a - i_a . R_a}{K_e} \quad (3)$$
$$\omega_m = \frac{K_T . e_a + (T_f) . R_a}{K_T . K_e}$$

$$\omega m = (0.06 * 32.4) + [(1.2 * 0.012)/(0.06 * 0.06)] = 536\ rad/s$$

Where, K_T = torque constant, T_f = static friction torque, j_m = rotational inertia, B_m = viscous friction.

$$T = K_T . i_a - T_f N - m \quad (4)$$

$$T = (0.06 * 2) - 0.012 = 0.108\ N - m$$

The mathematical model of the electric motor can also be described by the mathematical equations:

Electrical equation: $e_a(t) = R_a . i_a(t) + L \frac{di_t(t)}{dt} + e_b(t)$ (5)

Lap. Tra. of electrical equation: $E_a(s) = L . s . I_a(s) + R_a + I_a(s)$ (6)

$I_a(s) = \frac{1}{L.s.R_a} [E_a(s) - E_b(s)]$ (7)

Mechanical equation: $T(t) = j_m \frac{d\omega_{m\,(t)}}{dt} + B_m . \omega_{m\,(t)}$ (8)

Lap. Tra. of mechanical equation: $T(s) = (j_m . s + B_m) . \omega_m(s)$ (9)

$\omega_m(s) = [1/(j_m . s + B_m)] . T(s)$ (10)

Electromechanical relationships: $e_b(t) = K_E . \omega_m(t)$ (11)$T(t) = K_T . i_a(t)$ (11)

Lap. Tra. of electromechanical relationships:$e_b(s) = K_E . \omega_m(s)$ (13)$T(s) = K_T . i_a(s)$ (12)

A transfer function for a DC motor as show in equation 13 [43].

$$\frac{\omega_m(s)}{E_a(s)} = \frac{G(s)}{1+G(s).H(s)} = \frac{K_T}{L_a j_m . s^2 + (R_a j_m + B_m L_a) . s + (K_T . K_E + R_a . B_m)} \quad (13)$$

$$T.F\ for\ DC\ motor = \frac{16.13}{0.00333 s^2 + 0.201 s + 1} \quad (14)$$

Table 1. Parameters of DC motor

Parameters of DC motor	Meaning
ω_m	500 rad/sec
I_a	2 A
K_e	0.06 $V.\mathrm{s/red}$
K_T	0.06 $N.\mathrm{m/A}$
T_f	0.012 N-m
R_a	1.2 ohm
j_m	6.2*10-4 N-m-s/rad
B_m	1*10-4 N-m-s/rad
L_a	0.02 H

Hierarchical algorithm, as shown in Figure 4, is called wolf algorithm and can be represented by categories that include the leader, who is from the first level to the top of the hierarchy and is called alpha (a). This category is concerned with making decisions such as the spatial environment for living and hunting and can be male or female or both. The second category is a body considered in the second level of the hierarchy. Hierarchical duty helps the first category to make some decisions and is called beta (β). The third category is lower than its predecessors in terms of hierarchy called delta (δ), where it is considered a category subject to the orders of other groups and has a role to play, which is being a scapegoat. Below the pyramid is the lowest rank category, the fourth, which is the category of sheikhs, which performs the functions of guard and scouts. It is considered dominant over its predecessor, omega (ω), but is subject to both alpha and betas. In Figure 4 show the hierarchy of GWO. Also, the GWO had flow chart that show in Figure 5.

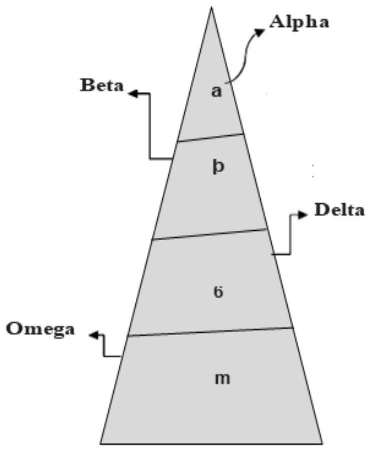


Figure 4. Hierarchy of GWO

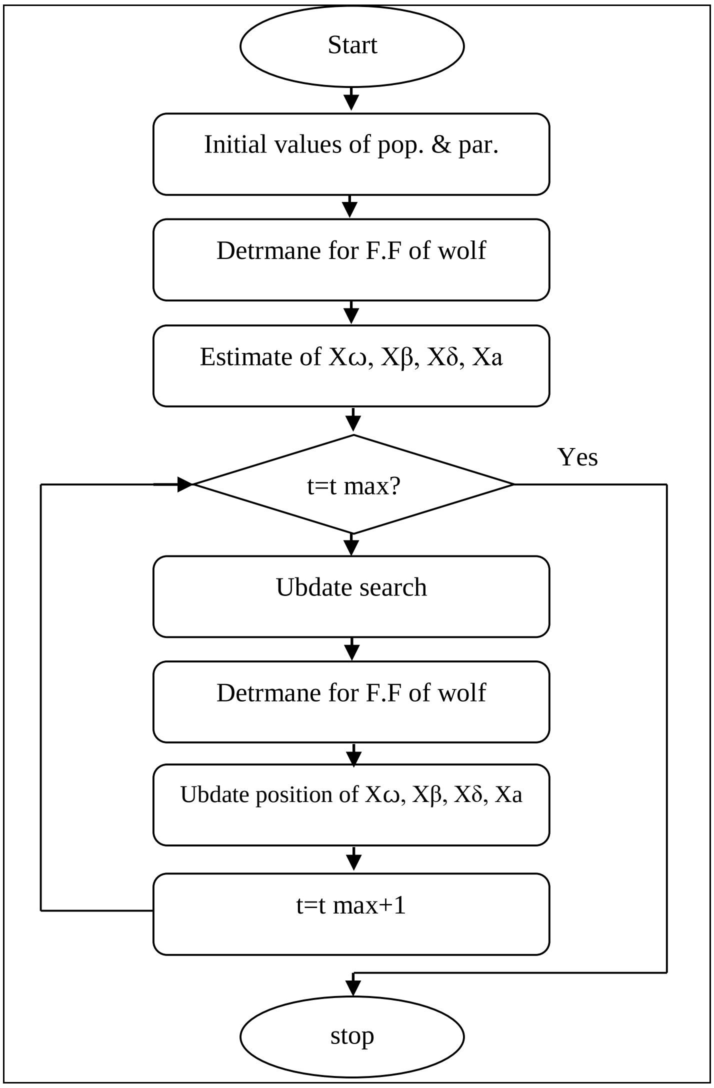


Figure 5. Flow chart for GWO

3. SIMULATION MODEL FOR DC MOTOR

3.1. Simulation model for DC motor with constan speed

The objective are design of PID controller and tuned it by GWO with transfer function (T.F). The T.F of the system in open loop as show in (16).

$$\mathrm{T.F\ for\ DC\ motor} = \frac{16.13}{0.00333s^2 + 0.201s + 1}$$

In Figures 10-12 the simulation model for DC motor. First the simulation model for DC motor without controller as show in Figure 10. Second the simulation model for DC motor with PID controller as show in Figure 11. Then, simulation model for DC motor with GWO-PID controller as show in Figure 12.

To improve the performance of the work of systems asks for the search for performance indications, which are placed to be indications to improve the performance of systems. To design appropriate controllers for any system are tested through one or more performance indications for a high effective system and within the required specifications. These indications can be recognized through the following equations for each type: i) Integral absolute error (IAE) as show in (15). Also in Figure 6 show block diagram forsimulation model of IAE; ii) Integral square error (ISE) as show in (16). Also in Figure 7 show block diagram for simulation model of ISE; iii) Integral of the product between the squared time and absolute error (ISTAE) as show in (17). Also in Figure 8 show block diagram for simulation model of ISTAE; and iv) ITAE integrates the absolute error multiplied by the time as show in (18). Also in Figure 9 show block diagram for simulation model of ITAE.

$$\text{IAE} = \int |e(t)| dt \tag{15}$$

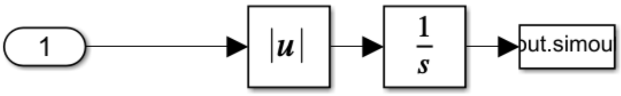


Figure 6. Block diagram for simulation model of IAE

$$\text{ISE} = \int e^2(t) dt \tag{16}$$

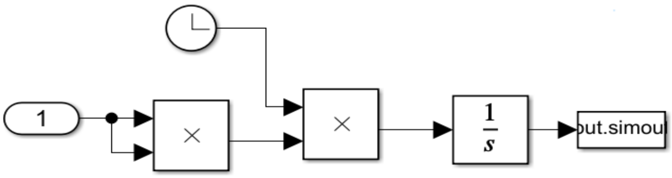


Figure 7. Block diagram for simulation model of ISE

$$\text{ISTAE} = \int t^2 |e(t)| dt \tag{17}$$

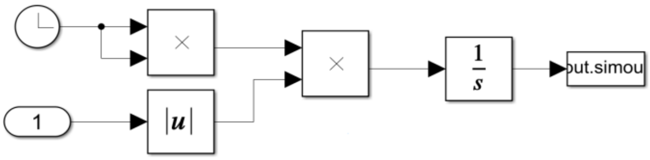


Figure 8. Block diagram for simulation model of ISTAE

$$\text{ITAE} = \int t |e(t)| dt \tag{18}$$

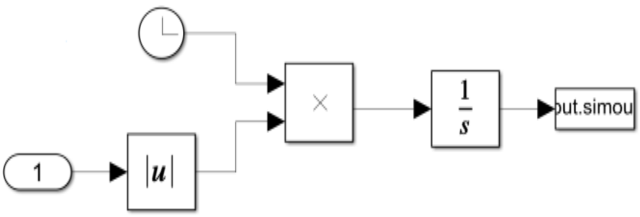


Figure 9. Block diagram for simulation model of ITAE

Figure 10 shows the block diagram for simulation model for DC motor without controller. Figure 11 shows the block diagram for simulation model for DC motor with PID controller. Figure 12 shows the block diagram for simulation model for DC motor with GWO-PID controller.

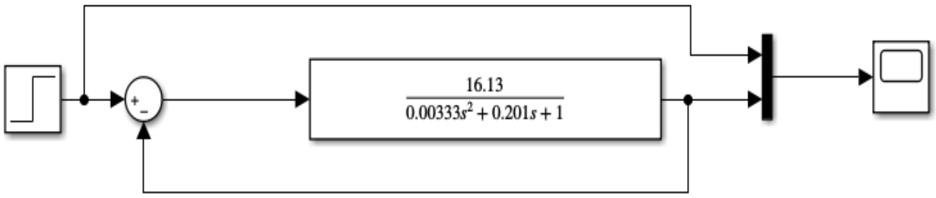


Figure 10. Block diagram for simulation model for DC motor without controller

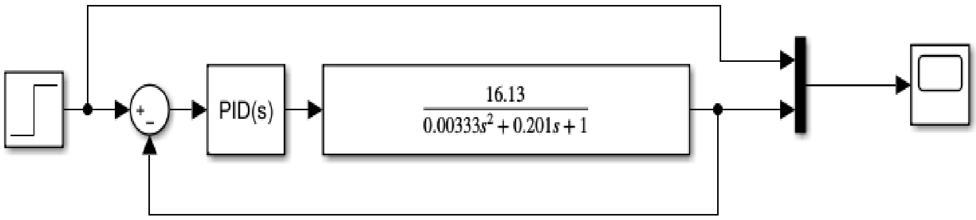


Figure 11. Block diagram for simulation model for DC motor with PID controller

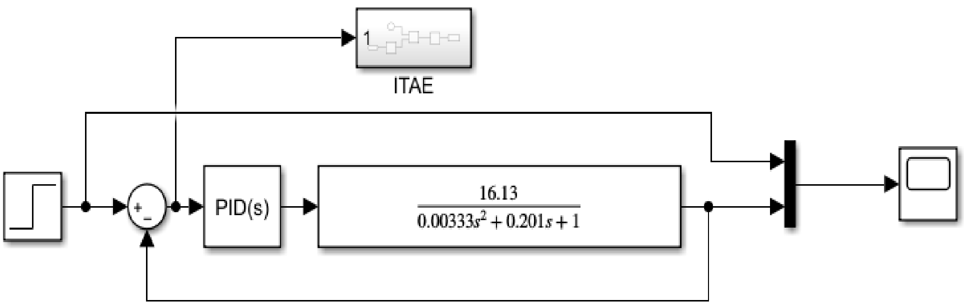
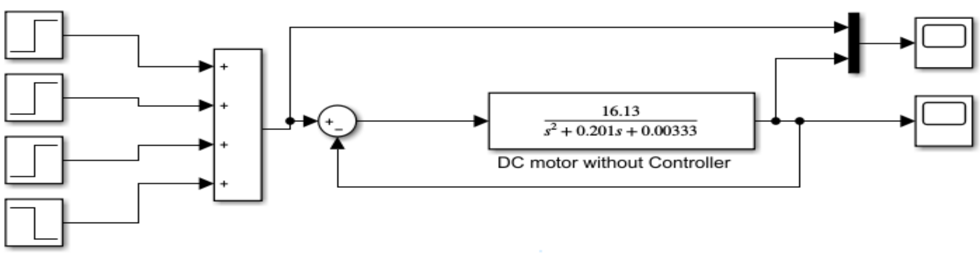


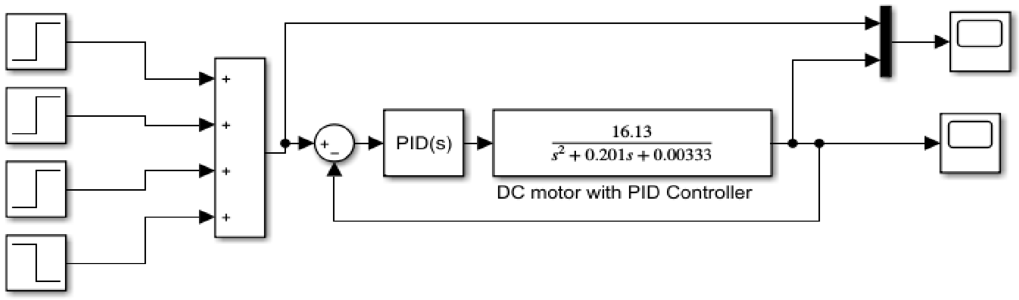
Figure 12. Block diagram for simulation model for DC motor with GWO-PID controller

3.2. Simulation model for DC motor with variable speed

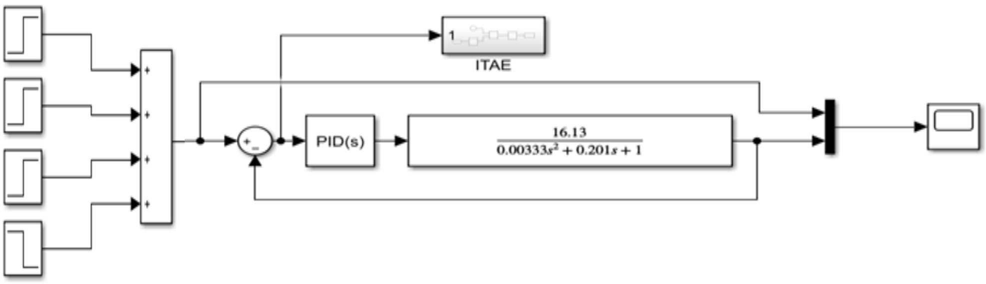
In this section there are three parts, in Figures 13-15 simulation model for DC motor of variable speed. First, the simulation model for DC motor of variable speed without controller as show in Figure 13. Second, the simulation model for DC motor of variable speed with PID controller as show in Figure 14. Last, the simulation model for DC motor of variable speed with GWO-PID controller as show in Figure 15.



Figures 13. Simulation model for DC motor of variable speed without controller



Figures 14. Simulation model for DC motor of variable speed without controller



Figures 15. Simulation model for DC motor of variable speed with GWO-PID controller

4. SIMULATION RESULTS OF DC MOTOR

4.1. Simulation results of DC motor with constant speed

This section includes three parts. First by using the simulation model in Figure 10. In this part the simulation results as show in Figure 16. Second by using the simulation model in Figure 11. In this part the simulation results as show in Figure 17. Then, by using the simulation model in DC motor with GWO-PID controller in this part the simulation results as show with comparative among for these simulation pars as show in the Table 2 and in Figure 18.

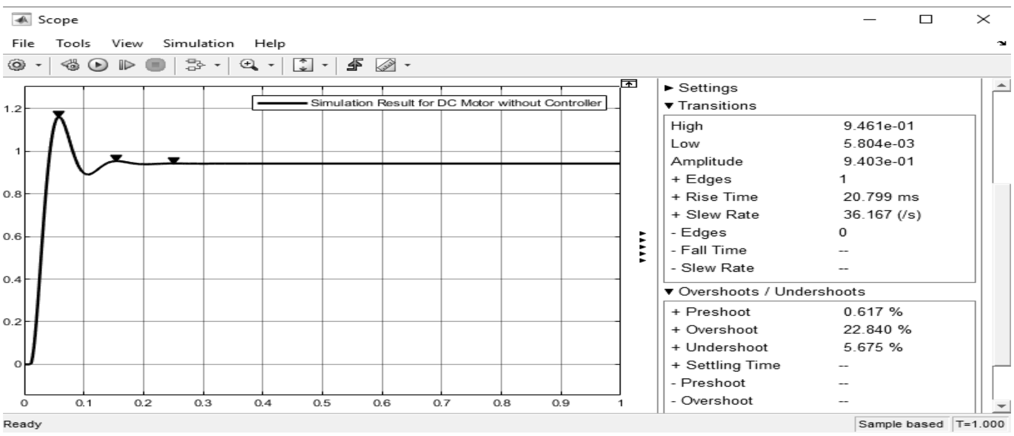


Figure 16. Simulation results for DC motor without controller

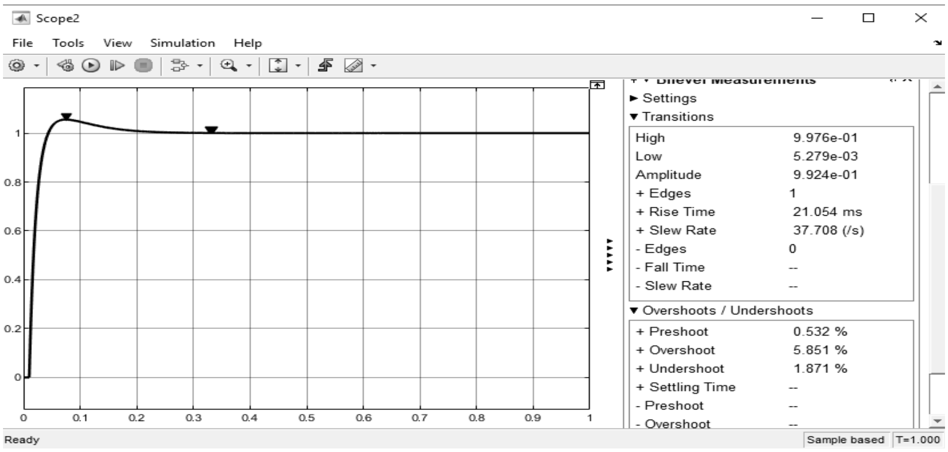


Figure 17. Simulation results for DC motor with PID controller

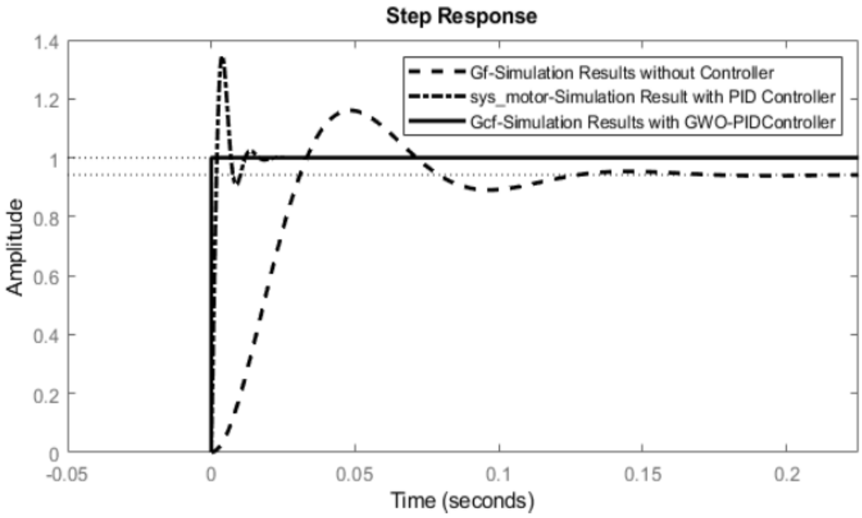


Figure 18. Simulation results for DC motor without controller, with PID and GWO-PID controller

Table 2. Simulation results with different algorithm

Algorithms	Over shoot (%)	Under shoot (%)	Rise time (sec)
DC motor without Controller	22.840	5.675	0.015
DC motor with PID Controller	5.851	1.871	0.0021
DC motor with GWO-pid controller		-	0.002

4.2. Simulation results of DC motor with variable speed

In this section there are three parts, in Figures 19-21 simulation results for DC motor of variable speed. First the simulation response for DC motor of variable speed without controller as show in Figure 19. Second the simulation response for DC motor of variable speed with PID controller as show in Figure 20. Third the simulation response for DC motor of variable speed with GWO-PID controller as show in Figure 21.

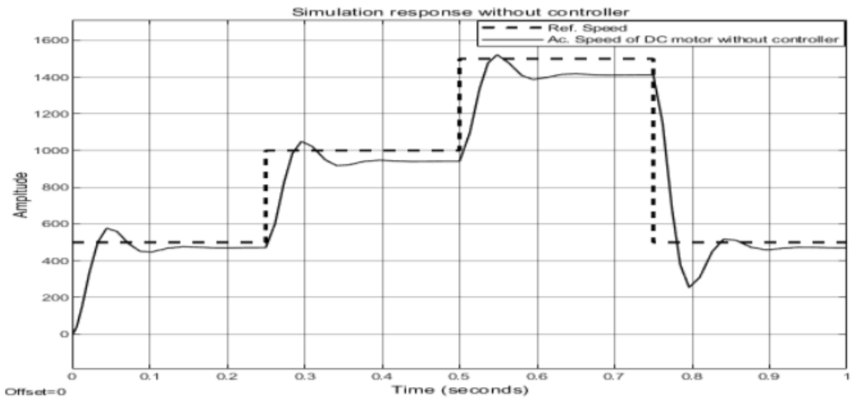


Figure 19. Simulation response for DC motor of variable speed without controller

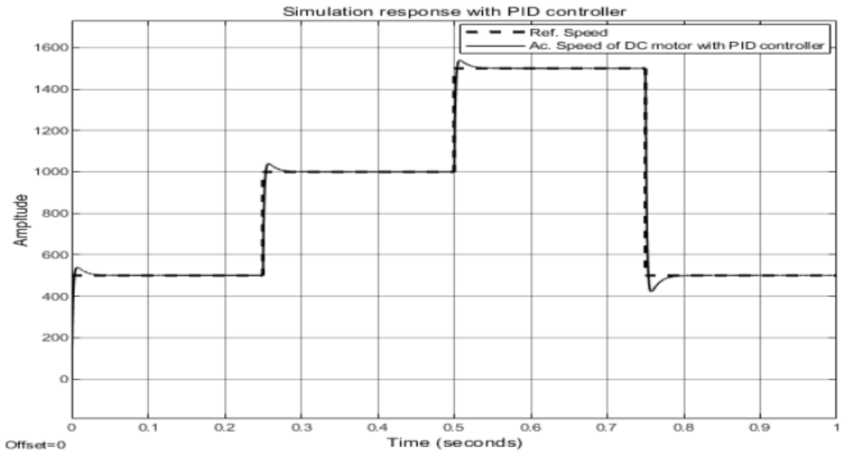


Figure 20. Simulation response for DC motor of variable speed with PID controller

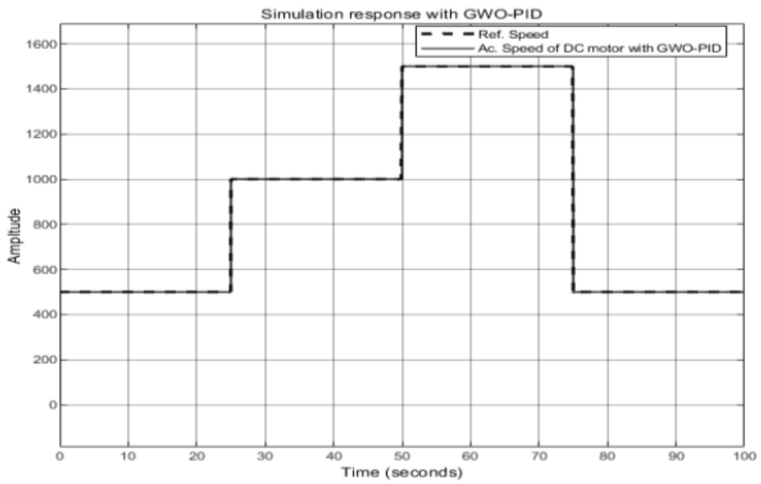


Figure 21. Simulation response for DC motor of variable speed with GWO-PID controller

In Figure 22 show the ITAE with each iteration. In Figure 23 show the step response. In Figure 24 show the wondow of T.F code for DC motor. In Figure 25 show the wondow of code for GWO-PID.

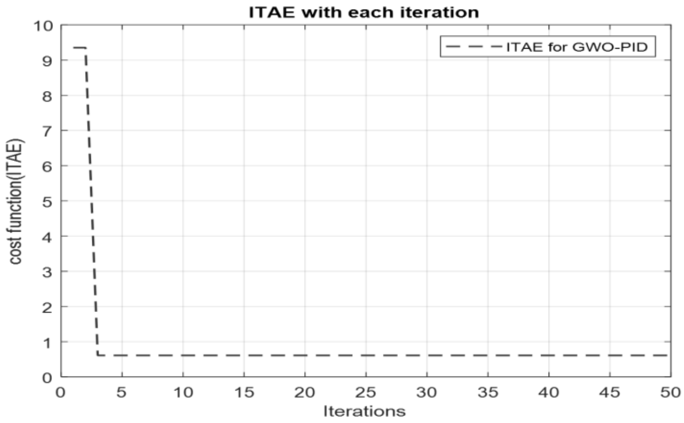


Figure 22. ITAE with each iteration

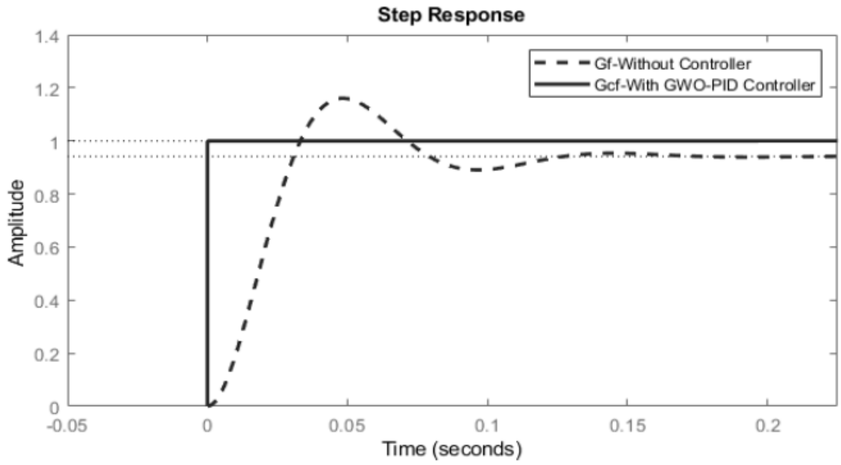


Figure 23. Step response

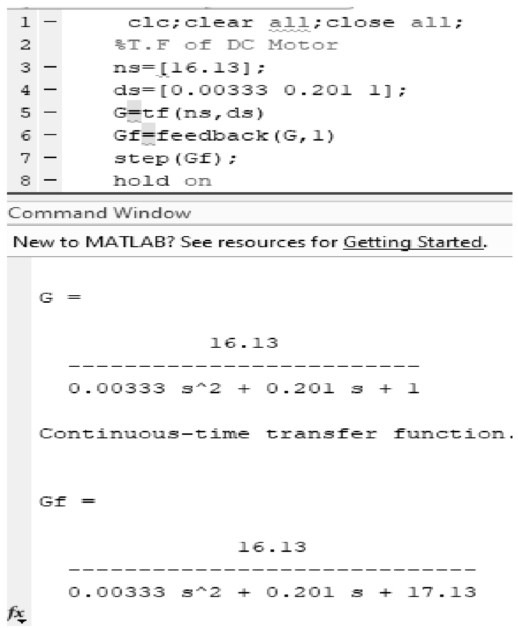


Figure 24. Window of T.F code for DC motor

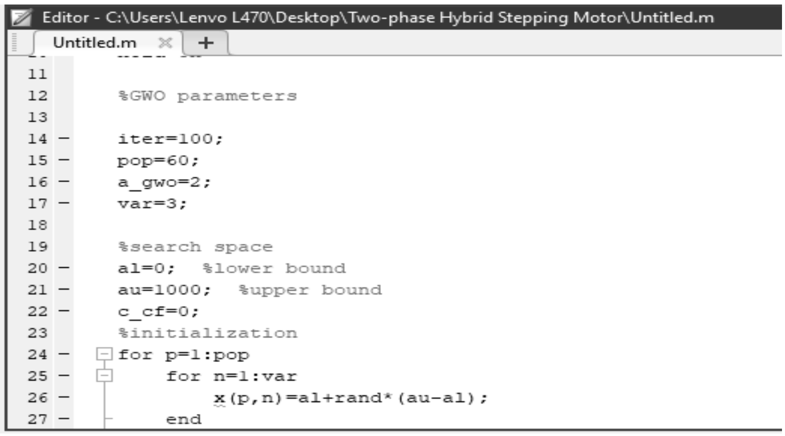


Figure 25. Window of code for GWO-PID

5. CONCLUSION

The current study was conducted by simulating the operation of a DC motor with working conditions for three cases that were selected and suggested to verify the preference for using the optimal advance and compare it with the two cases of no control systems. Others with the presence of control using the traditional system, a traditional control unit. The results demonstrated the superiority of the optimum advanced over the traditional progress unit in terms of response speed, time to reach a stable state, accuracy and quality. To adjust the parameters of the traditional controllers using the optimum advanced, an appropriate mechanism and technology from the advanced optimization techniques were chosen, as the Gray wolf technology algorithm was chosen as an optimization technique and ITAE to adjust the parameters of the traditional PID controller. The response speed, high accuracy, stability time and overtaking are higher and lower compared to different cases of working conditions that simulate real time.

REFERENCES

[1] H. M. A. Abbas, R. F. Chisab, and M. J. Mnati, “Monitoring and controlling the speed and direction of a DC motor through FPGA and comparison of FPGA for speed and performance optimization,” *International Journal of Electrical and Computer Engineering*, vol. 11, no. 5, pp. 3903–3912, 2021, doi: 10.11591/ijece.v11i5.pp3903-3912.

[2] F. N. Abdullah, G. A. Aziz, and S. W. Shneen, “Simulation model of servo motor by using matlab,” *Journal of Robotics and Control (JRC)*, vol. 3, no. 2, pp. 176–179, 2022, doi: 10.18196/jrc.v3i2.13959.

[3] A. H. Abed, “PSO-Based ekf estimator design for pmbldc motor,” *Engineering and Technology Journal*, vol. 34, no. 8, pp. 1651–1665, 2016.

[4] F. S. Ahmed, Z. S. Hussain, and T. K. M. Salih, “Enhancing performance for three-phase induction motor by changing the magnetic flux density and core material using comsol,” *International Journal of Electrical and Computer Engineering*, vol. 12, no. 1, pp. 62–72, 2022, doi: 10.11591/ijece.v12i1.pp62-72.

[5] H. Ali and M. K. Al-Khatat, “Design, simulation and implementation of dc motor drive,” *Engineering and Technology Journal*, vol. 32, no. 1, 2014.

[6] Q. Ali and M. Ezzaldean, “Direct current deadbeat predictive controller for bldc motor using single dc-link current sensor,” *Engineering and Technology Journal*, vol. 38, no. 8, pp. 1187–1199, 2020, doi: 10.30684/etj.v38i8a.471.

[7] B. Alsayid, W. A. Salah, and Y. Alawneh, “Modelling of sensored speed control of bldc motor using matlab/simulink,” *International Journal of Electrical and Computer Engineering*, vol. 9, no. 5, pp. 3333–3343, 2019, doi: 10.11591/ijece.v9i5.pp3333-3343.

[8] A. J. Blauch, M. Bodson, and J. Chiasson, “High-speed parameter estimation of stepper motors,” *IEEE Transactions on Control Systems Technology*, vol. 1, no. 4, pp. 270–279, 1993, doi: 10.1109/87.260272.

[9] A. J. Attiya, S. W. Shneen, B. A. Abbas, and Y. Wenyu, “Variable speed control using fuzzy-pid controller for two-phase hybrid stepping motor in robotic grinding,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 3, no. 1, pp. 102–118, 2016, doi: 10.11591/ijeecs.v3.i1.pp102-118.

[10] A. J. Attiya, Y. Wenyu, and S. W. Shneen, “Compared with pi, fuzzy-pi and pso-pi controllers of robotic grinding force servo system,” *TELKOMNIKA Indonesian Journal of Electrical Engineering*, vol. 16, no. 1, p. 65, Oct. 2015, doi: 10.11591/tijee.v16i1.1589.

[11] A. J. Attiya, Y. Wenyu, and S. W. Shneen, “Fuzzy-pid controller of robotic grinding force servo system,” *TELKOMNIKA Indonesian Journal of Electrical Engineering*, vol. 15, no. 1, Jul. 2015, doi: 10.11591/telkomnika.v15i1.8051.

[12] A. J. Attiya, Y. Wenyu, and S. W. Shneen, “PSO_PI controller of robotic grinding force servo system,” *TELKOMNIKA Indonesian Journal of Electrical Engineering*, vol. 15, no. 3, p. 515, 2015, doi: 10.11591/tijee.v15i3.1570.

[13] Y. Bekakra and D. Ben Attous, “Optimal tuning of pi controller using pso optimization for indirect power control for dfig based wind turbine with mppt,” *International Journal of System Assurance Engineering and Management*, vol. 5, no. 3, pp. 219–229, 2014, doi: 10.1007/s13198-013-0150-0.

[14] V. Chopra, S. K. Singla, and L. Dewan, “Comparative analysis of tuning a pid controller using intelligent methods,” *Acta Polytechnica Hungarica*, vol. 11, no. 8, pp. 235–249, 2014.

[15] H. S. Dakheel, Z. B. Abdullah, N. S. Jasim, and S. W. Shneen, "Simulation model of ann and pid controller for direct current servo motor by using matlab/simulink," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 20, no. 4, p. 922, Aug. 2022, doi: 10.12928/telkomnika.v20i4.23248.

[16] J. Deng, Y. Lei, J.-S. Kang, and M. Yu, "A harmonic current suppression method for single-phase pwm rectifier based on feedback linearization," in *2022 International Conference on Power Energy Systems and Applications (ICoPESA)*, Feb. 2022, pp. 90–95, doi: 10.1109/ICoPESA54515.2022.9754411.

[17] H. Faisal, F. Mohammed, and J. Mohammed, "Design and implementation of an electromechanical brake system," *Engineering and Technology Journal*, vol. 40, no. 1, pp. 31–39, 2022, doi: 10.30684/etj.v40i1.2150.

[18] L. A. Garcia-Reyes, A. Beltrán-Telles, F. Bañuelos-Ruedas, M. Reta-Hernández, J. M. Ramírez-Arredondo, and R. Silva-Casarín, "Level-shift pwm control of a single-phase full h-bridge inverter for grid interconnection, applied to ocean current power generation," *Energies*, vol. 15, no. 5, p. 1644, Feb. 2022, doi: 10.3390/en15051644.

[19] N. Jain, G. Parmar, R. Gupta, and I. Khanam, "Performance evaluation of gwo/pid approach in control of ball hoop system with different objective functions and perturbation," *Cogent Engineering*, vol. 5, no. 1, p. 1465328, Jan. 2018, doi: 10.1080/23311916.2018.1465328.

[20] M. A. Khelif, A. Bendiabdellah, and B. D. E. Cherif, "Short-circuit fault diagnosis of the dc-link capacitor and its impact on an electrical drive system," *International Journal of Electrical and Computer Engineering*, vol. 10, no. 3, pp. 2807–2814, 2020, doi: 10.11591/ijece.v10i3.pp2807-2814.

[21] M. Kushwah and A. Patra, "Tuning pid controller for speed control of dc motor using soft computing techniques-a review," *Advance in Electronic and Electric Engineering*, vol. 4, no. 2, pp. 141–148, 2014.

[22] T. C. Kwang, M. L. Mohd Jamil, and A. Jidin, "Improved magnetic behavior of hemicycle pm motor via stator modification," *International Journal of Electrical and Computer Engineering*, vol. 10, no. 3, pp. 3323–3332, 2020, doi: 10.11591/ijece.v10i3.pp3323-3332.

[23] W. Li, H. Xie, G. Zhang, S. Yan, and Z. Yin, "3-D shape matching of a blade surface in robotic grinding applications," *IEEE/ASME Transactions on Mechatronics*, vol. 21, no. 5, pp. 2294–2306, Oct. 2016, doi: 10.1109/TMECH.2016.2574813.

[24] C. L. Lin, H. Y. Jan, and N. C. Shieh, "GA-based multiobjective pid control for a linear brushless dc motor," *IEEE/ASME Transactions on Mechatronics*, vol. 8, no. 1, pp. 56–65, 2003, doi: 10.1109/TMECH.2003.809136.

[25] P. M. Meshram and Rohit G. Kanojiya, "Tuning of pid controller using ziegler-nichols method for speed control of dc motor," in *IEEE-International Conference On Advances In Engineering, Science And Management (ICAESM -2012)*, 2012, pp. 117–122.

[26] A. L. Shuraiji and J. A. Mohammed, "Modeling of dc elevator motor drive for mid-rise building," *Engineering & Technology Journal*, vol. 31, no. 12, pp. 2320–2342, 2013.

[27] S. Mondal and M. Chattopadhyay, "Comparative study of three different bridge-less converters for reduction of harmonic distortion in brushless dc motor," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 20, no. 3, pp. 1185–1193, 2020, doi: 10.11591/ijeecs.v20.i3.pp1185-1193.

[28] D. S. Nayak and R. Shivarudraswamy, "A solar fed bldc motor drive for mixer grinder using a buck converter," *International Journal of Electrical and Computer Engineering*, vol. 10, no. 2, pp. 1113–1121, 2020, doi: 10.11591/ijece.v10i2.pp1113-1121.

[29] D. S. Nayak and R. Shivarudraswamy, "Solar fed bldc motor drive for mixer grinder using a buck-boost converter," *Bulletin of Electrical Engineering and Informatics*, vol. 9, no. 1, pp. 48–56, 2020, doi: 10.11591/eei.v9i1.1667.

[30] Trong Duy Nguyen, King-Jet Tseng, Shao Zhang, and Hoan Thong Nguyen, "A novel axial flux permanent-magnet machine for flywheel energy storage system: Design and analysis," *IEEE Transactions on Industrial Electronics*, vol. 58, no. 9, pp. 3784–3794, Sep. 2011, doi: 10.1109/TIE.2010.2089939.

[31] L. Peng, L. Ma, W. Song, and H. Liu, "A simple model predictive instantaneous current control for single-phase pwm converters in stationary reference frame," *IEEE Transactions on Power Electronics*, vol. 37, no. 7, pp. 7629–7639, Jul. 2022, doi: 10.1109/TPEL.2022.3141793.

[32] A. K. K. A. Raheem, S. W. Shneen, M. H. Jaber, and A. H. Reja, "Design and simulation of a second-order universal switched-capacitor filter as a 10-pin dual-in-line package integrated circuit," *Engineering and Technology Journal*, vol. 30, no. 18, pp. 3175–3191, 2012.

[33] C. Reeves, *Modern Heuristic Techniques for Combinatorial Problems*. 1993.

[34] S. W. Shneen, A. Z. Salman, Q. A. Jawad, and H. Shareef, "Advanced optimal by pso-pi for dc motor," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 16, no. 1, pp. 165–175, 2019, doi: 10.11591/ijeecs.v16.i1.pp165-175.

[35] S. W. Shneen, H. S. Dakheel, and Z. B. Abdulla, "Design and implementation of variable and constant load for induction motor," *International Journal of Power Electronics and Drive Systems*, vol. 11, no. 2, pp. 762–773, 2020, doi: 10.11591/ijpeds.v11.i2.pp762-773.

[36] S. W. Shneen, M. Q. Sulttan, and M. H. Jaber, "Variable speed control for 2Ph-HSM in RGS: A comparative simulation study," *International Journal of Electrical and Computer Engineering*, vol. 10, no. 3, pp. 2285–2295, 2020, doi: 10.11591/ijece.v10i3.pp2285-2295.

[37] F. A. Silaban, S. Budiyanto, and W. K. Raharja, "Stepper motor movement design based on FPGA," *International Journal of Electrical and Computer Engineering*, vol. 10, no. 1, pp. 151–159, 2020, doi: 10.11591/ijece.v10i1.pp151-159.

[38] R. Thangaraj, T. R. Chelliah, M. Pant, A. Abraham, and C. Grosan, "Optimal gain tuning of PI speed controller in induction motor drives using particle swarm optimization," *Logic Journal of IGPL*, vol. 19, no. 2, pp. 343–356, Apr. 2011, doi: 10.1093/jigpal/jzq031.

[39] J. Wang, G. Zhang, H. Zhang, and T. Fuhlbrigge, "Force control technologies for new robotic applications," in *2008 IEEE International Conference on Technologies for Practical Robot Applications, TePRA*, 2008, pp. 143–149, doi: 10.1109/TEPRA.2008.4686689.

[40] W. K. Wibowo and S. K. Jeong, "Genetic algorithm tuned PI controller on PMSM simplified vector control," *Journal of Central South University*, vol. 20, no. 11, pp. 3042–3048, 2013, doi: 10.1007/s11771-013-1827-x.

[41] E. M. Ismaeil, M. S. Zaky, and M. M. Khater, "DSP-Based real-time control of a two phase hybrid stepping motor," *Journal of Electrical Engineering*, vol. 10, no. 4, p. 6, 2010.

[42] Z. Tuanshan, Z. Na, and W. Yuting, "Study of driving bipolar stepper motors based on enhanced STM32," *Electronic Measurement Technology*, vol. 33, no. 10, pp. 16–18, 2010.

[43] S. Y. Zhang and X. M. Wang, "Study of fuzzy-pid control in matlab for two-phase hybrid stepping motor," *Applied Mechanics and Materials*, vol. 341–342, pp. 664–667, 2013, doi: 10.4028/www.scientific.net/AMM.341-342.664.

[44] Y. Zhu, Z. Wang, C. Wang, Y. Zhu, and X. Cao, "A novel improved coordinate rotated algorithm for pwm rectifier thd reduction," *Electronics*, vol. 11, no. 9, p. 1435, Apr. 2022, doi: 10.3390/electronics11091435.

BIOGRAPHIES OF AUTHORS

Ghada Adel Aziz received BS.c, MS.c, PhD. Degrees in Electrical Engineering and Education from Electromechanical Engineering Department (previously named Technical Education Department) in 1992, 1999, and 2007, respectively, University of Technology, Baghdad, Iraq. I was appointed and worked in the Electromechanical Engineering Department (previously named Technical Education Department) since 1992. She can be contscted at email: 50070@uotechnology.edu.iq

Salam Waley Shneen received PhD, Degree in Electrical Engineering-Power Electronic, School of Electrical and Electronic Engineering, Huazhong University of Science and Technology (HUST). Nov 2005 MSc, Degree in Engineering Educational Technology-Electrical Engineering, Technical Education Department, University of Technology, Iraq-Baghdad. July 1998 BSc, Degree in Electrical Engineering and Education, Technical Education Department, University of Technology, Iraq-Baghdad. Oct 1994 Diploma in Electrical Technology, Technical Instructors Training Institute, Iraq Baghdad. 1992 High School Bakaloria Degree Preparatory Technical School (Electrical Section), Almashtal Technical Secondary School Iraq-Baghdad. He can be contacted at email: salam.w.shneen@uotechnology.edu.iq

Fatin Nabeel Abdullah received MSc, Degree in Engineering Educational Technology-Electrical Engineering, Technical Education Department, University of Technology, Iraq-Baghdad. Jun 1995 BSc, Degree in Electrical Engineering and Education, Technical Education Department, University of Technology, Iraq-Baghdad. 1991 High School Bakaloria, Degree Dejla Secondary School Iraq-Baghdad. She can be contacted at email: 50060@uotechnology.edu.iq

Dina Harith Shaker Degree in Department of Electromechanical Engineering, University of Technology, Baghdad, Iraq. She can be contacted at email: 50061@uotechnology.edu.iq